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I. INTRODUCTION

For a period of some 20 years, commencing in 1962, certain U.S. Navy and commercial aircraft experienced infrequent fuel system problems in the Western Pacific area of operations. It was subsequently demonstrated[(1-3)*] that the problems were associated with the development of significant fuel peroxides which degraded elastomeric components in the systems. As a consequence of this identified problem area, the Navy has performed and sponsored work to obviate future difficulties with respect to peroxide attack of fuel system components. Such work has included the development of a technique to predict the peroxidation potential of a fuel,[(4)] and an evaluation of the effectiveness of approved JP-5 fuel antioxidants in preventing peroxide formation.[(5)] The work reported herein is essentially supplemental to the latter study.

Currently-approved antioxidants for use in JP-5 are of the hindered phenol type. An evaluation of the effectiveness of the various compounds in this category, reported in Reference 5, showed that a totally hindered material, 2-6-di-tert-butyl-4-methylphenol (AO-B), was most effective in the suppression of hydroperoxide formation. In the final phase of that study, AO-B was evaluated in comparison with a partially hindered compound, 60 percent minimum 2-4-di-tert-butylphenol and 40 percent maximum mixture of tert-butylphenols (AO-D), after 8 weeks of fuel storage at 60°C. AO-B was superior to AO-D at both concentrations (8 and 24 ppm) investigated. In general, however, the study found that AO-B and AO-D were the most effective antioxidants of those types approved for use in JP-5 fuel.

The objective of the work reported herein was to determine whether the degraded AO-B and AO-D additives showed any tendency to promote elastomer attack as a consequence of antioxidant consumption in the process of inhibition. Employing one stable and one unstable fuel (with respect to peroxidation tendency) with and without inhibitor, samples were prestressed at moderate temperature to ensure that significant additive reaction had occurred, at least for the unstable fuel. Following this pretreatment, typical fuel system elastomer specimens were immersed in the fuel samples and stored at 43°C for periods ranging from 7 to 270 days. Elastomer properties were determined after storage.

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* Superscript numbers in parenthesis refer to the List of References.

II. TEST FUELS

Two kerosene-type base fuels were used to investigate possible antioxidant/elastomer interactions. One was a straight-run fuel known to resist peroxide formation and one was a hydrocracked kerosene which had a tendency toward peroxidation in the absence of an inhibitor. Prior to use, both base fuels were alumina treated to remove polar components and existent peroxides. Select fuel samples were then blended with antioxidants AO-B or AO-D at the maximum allowable concentration of 8.4 lb/ 1000 bbl (24 mg/L).

All fuel samples, save one, were prestressed at 43° or 60°C for several weeks to make certain that antioxidant consumption in the unstable fuel had occurred. This was evidenced by peroxide buildup in the uninhibited, unstable fuel. The goal of the prestressing was to reach a peroxide value of 100 to 200 ppm for this sample. After prestressing, the condition of the fuel samples was as follows:

Fuel No.	Fuel Type	Antioxidant	Peroxide Content, ppm*
1	Stable	None	1
2	Stable	AO-B	1
3	Unstable	None	144
4	Unstable	AO-B	1
5	Unstable	AO-D	2
6	Unstable	None	0

* All fuels prestressed except No. 6.

The peroxide content of Fuel 3 suggests substantial reaction of the antioxidants in the unstable Fuels 4 and 5. Fuel 6, which was not prestressed, was stored at 5°C during the pretreatment period.

As previously identified, the above antioxidant designations correspond to those used in Reference 5:

AO-B - 2-6-di-tert-butyl-4-methylphenol
AO-D - 60 percent min 2-4-di-tert-butylphenol
40 percent max mixed tert-butylphenols

The aromatic contents of the two base fuels, which can also affect elastomer integrity, were not significantly different. The values, determined by ASTM Method D 1319, were 17.9 vol percent for the stable fuel and 16.1 vol percent for the unstable fuel.

III. ELASTOMER MATERIALS

Elastomer materials selected for this investigation covered four fuel system component types: O-ring materials, a fuel pump diaphragm material, fuel tank sealants, and fuel cell materials. Most of the material types were evaluated in previous work[6] on the effects of fuel aromatics on elastomer integrity. TABLE 1 provides a listing of individual elastomer compounds and the properties evaluated for each of the four material types. These evaluations were performed in accordance with standard procedures described by ASTM Methods D 471 (volume change), D 412 (tensile strength, elongation), D 2240 (hardness), and D 429 (peel strength).

Except for the peel strength specimens which were evaluated singly, all O-ring and dumbbell specimens were tested in triplicate for experimental confidence. The specimens and fuel samples were stored in glass bottles within a darkened room at $43^\circ \pm 1^\circ C$. Seven samples of each category were placed in storage to permit removal and evaluation after 7, 14, 30, 60, 120, 180, and 270 days of storage. At weekly intervals, the bottle caps for all samples remaining in storage were removed for a period of 15 to 30 minutes to allow for replenishment of vapor space oxygen (air).

TABLE 1. Elastomer Evaluations

Material Type	Property Evaluation
O-Rings	
Buna-N, low nitrile Buna-N, high nitrile Fluorocarbon (Viton) Fluorosilicone	Tensile strength, elongation, hardness, volume change
Diaphragm	
Neoprene	Tensile strength, elongation
Fuel Tank Sealants	
CS 3204, B-2 PS 890, B-2 PR 1422, B-2 PS 899, B-2 PR 1221, B-2	Tensile strength, elongation hardness, volume change, peel strength
Fuel Cell Materials	
51956, Buna-N 80C29, Polyurethane FT 76, Buna-N Pliocel, Nylon	Tensile strength, elongation, volume change

IV. RESULTS AND DISCUSSION

In the subsequent discussion of results, it is emphasized that observations are subjectively derived relative to fuel, additive, or elastomer type. There are no established elastomer performance standards for the storage temperature or durations used in this study; thus, no pass/fail type criteria are applicable.

Peroxide Formation

To establish the extent of fuel peroxidation over the maximum storage period (270 days) at 43°C, one typical set of fuel samples was analyzed for peroxide content, with the following results:

Fuel No.	Fuel Type	Antioxidant	Peroxide Content, ppm	
			Initial*	270 Days
1	Stable	None	1	4
2	Stable	AO-B	1	2
3	Unstable	None	144	423
4	Unstable	AO-B	1	1
5	Unstable	AO-D	2	4
6	Unstable	None	0	33

* All fuels prestressed except No. 6.

With respect to additive effectiveness, the above data agree with previous work reported by NAPC.(5) AO-B suppressed peroxidation throughout the storage period, while AO-D was just slightly less effective. Both of the stable fuel samples (1 and 2) indicated negligible peroxide levels and, thus, any reaction products formed by consumption of AO-B in Fuel 2 were probably minimal. Both the prestressed (3) and unstressed (6) samples of the unstable fuel without an antioxidant showed measurable peroxide increases after 270 days. As a consequence, any effect on elastomer integrity due to antioxidant reaction products should be evidenced by the two inhibited fuels (4 and 5).

Results for O-Ring Materials

Elastomer property results for the four O-ring materials examined in the study are given in TABLES 2 to 5. Elongation and retained tensile strength results indicate no apparent trend with respect to fuel type except for Fuel 3, the uninhibited high-peroxide fuel. This sample consistently showed the lowest result for the low nitrile Buna-N material (TABLE 2), and was exceptionally low for the 14-day storage period and fluorosilicone (TABLE 5).

Fig. 1 presents the volume change results for all O-ring materials investigated. The data are generally clustered according to elastomer type, with little variation between fuels. There is some indication that Fuels 1 and 2 with low nitrile Buna-N were somewhat higher in volume change—possibly due to the slightly higher aromatic content of the base fuel.

Fig. 2 illustrates the O-ring hardness change data. Again, the values are grouped according to elastomer type, but the high-peroxide Fuel 3 with low nitrile Buna-N is conspicuously higher in hardness change than all other combinations.

Results for Neoprene Diaphragm Material

Elongation and tensile strength results for this material are given in TABLE 6. Ultimate elongation values were low relative to other material types. The data showed some decrease with storage time but indicated no trend with respect to fuel type. Tensile strength retention data showed some isolated cases of significant reduction, e.g., Fuel 2 at 7 days, but there was no consistent effect attributable to fuel type or storage time.

Results for Fuel Tank Sealant Materials

Data for the five fuel tank sealant elastomers are given in TABLES 7 through 11. Hardness and elongation results for these materials were generally unchanged throughout the storage period. Retained tensile strength and peel strength indicated some deterioration with storage time but no unique effect for fuel type.

TABLE 2. Property Data for Low Nitrile Buna-N O-Ring Material

Storage Period, days	Fuel	Vol Change, %	Hardness Change, Shore A	Elongation, %	Retained Tensile Strength, %
7	1	22.4	1.4	241	71.9
	2	24.6	-0.3	269	85.2
	3	15.3	3.6	223	91.8
	4	16.6	3.6	265	85.2
	5	16.7	1.2	291	92.3
	6	16.3	2.5	277	91.2
14	1	22.6	4.9	285	88.2
	2	22.0	1.8	278	85.7
	3	17.7	10.5	261	66.4
	4	16.8	4.0	287	87.6
	5	16.9	3.8	273	86.3
	6	17.0	5.2	273	84.6
30	1	22.7	8.0	260	87.6
	2	22.6	6.6	228	75.0
	3	20.4	22.7	247	46.2
	4	16.7	8.9	277	92.6
	5	17.1	8.8	264	90.0
	6	17.6	8.1	260	85.0
60	1	22.3	8.9	251	86.1
	2	22.0	7.1	254	73.4
	3	18.8	18.2	218	48.8
	4	17.0	6.9	243	78.7
	5	16.7	6.5	262	82.3
	6	16.6	8.1	257	84.9
120	1	20.7	12.1	192	78.4
	2	20.8	10.0	208	86.1
	3	20.5	26.4	181	40.6
	4	16.0	9.4	200	72.2
	5	15.3	9.5	178	72.3
	6	14.8	11.5	177	72.7
180	1	23.3	13.6	280	88.5
	2	23.6	13.5	244	71.9
	3	22.3	34.2	229	32.5
	4	18.4	12.8	251	79.6
	5	18.9	14.8	254	77.7
	6	18.0	11.8	257	77.0
270	1	23.1	2.2	207	79.1
	2	22.8	0.3	191	75.9
	3	19.9	23.7	166	32.1
	4	17.8	0.1	210	86.9
	5	17.6	2.2	211	85.5
	6	17.5	1.8	214	86.6

TABLE 3. Property Data for High Nitrile Buna-N O-Ring Material

Storage Period, days	Fuel	Vol Change, %	Hardness Change, Shore A	Elongation, %	Retained Tensile Strength, %
7	1	0.1	6.8	242	99.8
	2	-0.2	6.0	257	100.7
	3	-0.1	6.4	230	96.8
	4	-1.9	6.3	215	99.3
	5	-1.5	7.1	251	101.2
	6	-1.5	4.1	257	101.9
14	1	-0.6	0.8	250	109.5
	2	-0.6	0.8	213	97.3
	3	-1.1	-0.1	235	96.6
	4	-2.4	-1.8	271	106.8
	5	-2.5	-0.1	272	108.9
	6	-2.5	-1.2	240	97.3
30	1	-1.1	-0.5	258	101.9
	2	-1.1	-0.1	245	98.2
	3	-1.7	-3.5	225	90.8
	4	-3.6	-2.1	237	98.5
	5	-3.6	-0.2	262	106.4
	6	-3.5	-1.2	229	97.5
60	1	-2.7	-1.4	237	102.5
	2	-2.7	-1.3	243	104.2
	3	-3.9	-1.5	231	104.6
	4	-5.1	-5.5	243	108.0
	5	-4.9	-1.1	238	110.0
	6	-4.8	-0.7	238	107.6
120	1	-5.7	-7.1	238	103.2
	2	-1.5	-5.9	228	99.0
	3	-5.7	-4.5	228	98.7
	4	-5.2	-7.0	259	108.4
	5	-4.1	-6.0	214	99.0
	6	-1.7	-7.9	227	105.2
180	1	-2.1	-1.8	216	100.6
	2	-2.2	-2.8	230	105.5
	3	-4.7	-4.2	216	99.0
	4	-4.8	-3.8	227	108.7
	5	-4.9	-2.6	233	111.8
	6	-4.6	-4.1	239	112.9
270	1	-5.3	-11.7	165	104.7
	2	-2.7	-10.3	168	101.9
	3	-5.8	-11.9	154	94.1
	4	-6.3	-11.6	170	108.9
	5	-5.2	-12.1	173	110.0
	6	-5.2	-13.2	172	108.6

TABLE 4. Property Data for Viton O-Ring Material

Storage Period, days	Fuel	Vol Change, %	Hardness Change, Shore A	Elongation, %	Retained Tensile Strength, %
7	1	1.5	4.1	128	97.5
	2	1.5	5.2	119	90.7
	3	1.7	2.3	133	96.1
	4	1.6	1.8	117	89.3
	5	1.6	2.3	117	81.8
	6	1.5	5.3	110	80.4
14	1	0.5	-1.0	168	105.1
	2	0.5	-2.6	172	104.3
	3	0.1	-3.9	160	106.9
	4	0.6	-4.4	157	102.0
	5	0.1	-2.7	169	105.6
	6	0.5	-4.7	164	106.9
30	1	1.2	-0.2	146	83.1
	2	1.1	0.8	139	79.4
	3	1.1	2.5	134	95.0
	4	0.9	1.0	167	89.1
	5	0.9	0.7	151	84.1
	6	0.9	2.2	164	96.7
60	1	0.8	4.8	147	92.7
	2	0.8	2.6	170	92.5
	3	1.5	4.5	119	93.5
	4	0.2	0.9	128	94.8
	5	0.5	5.0	123	94.7
	6	0.3	3.2	130	94.2
120	1	1.9	-4.7	186	102.7
	2	1.4	-4.3	179	103.1
	3	2.4	-2.6	126	94.5
	4	2.8	-2.4	190	101.6
	5	1.7	-5.0	155	88.5
	6	0.7	-2.9	182	96.8
180	1	2.5	2.9	137	95.0
	2	2.7	1.2	142	98.4
	3	3.9	3.2	134	93.8
	4	2.2	1.2	137	96.0
	5	2.1	2.6	130	91.8
	6	3.6	1.8	137	96.9
270	1	3.5	0.8	140	94.8
	2	3.1	0.4	131	90.8
	3	3.2	0.4	140	91.5
	4	3.6	0.2	137	93.8
	5	3.0	1.2	120	81.7
	6	3.4	-0.2	132	92.1

TABLE 5. Property Data for Fluorosilicone O-Ring Material

Storage Period, days	Fuel	Vol Change, %	Hardness Change, Shore A	Elongation, %	Retained Tensile Strength, %
7	1	4.4	2.6	94	85.6
	2	4.4	2.1	112	93.5
	3	4.6	4.0	109	97.5
	4	4.6	3.4	107	94.2
	5	4.6	4.2	112	98.6
	6	4.3	2.5	112	98.2
14	1	5.2	3.4	158	98.7
	2	5.4	3.9	164	97.7
	3	5.4	2.2	49	84.7
	4	5.4	2.5	146	98.4
	5	5.4	2.4	158	107.6
	6	5.2	2.6	162	105.7
30	1	4.4	1.6	148	94.3
	2	4.4	1.6	161	94.9
	3	4.4	2.1	159	105.5
	4	4.1	1.9	137	96.4
	5	4.0	2.1	138	104.0
	6	4.2	1.4	99	103.9
60	1	5.0	5.5	148	92.8
	2	5.1	2.8	147	86.1
	3	4.5	4.9	150	100.2
	4	4.7	4.4	152	95.8
	5	4.9	4.9	146	100.0
	6	5.1	6.4	149	100.6
120	1	10.2	-0.4	143	84.3
	2	13.5	0.2	143	92.5
	3	12.0	2.3	142	98.5
	4	13.0	1.0	138	98.5
	5	13.0	0.7	147	99.1
	6	9.5	2.2	153	98.0
180	1	5.0	5.5	133	85.8
	2	4.9	4.1	144	89.4
	3	5.2	7.6	156	94.0
	4	5.0	7.7	141	93.2
	5	5.4	7.4	138	91.0
	6	4.6	8.9	157	98.1
270	1	3.5	4.9	110	94.6
	2	4.1	3.2	115	102.2
	3	4.8	4.4	111	98.8
	4	4.6	3.9	111	95.1
	5	5.4	1.4	97	81.2
	6	4.4	4.5	119	103.5

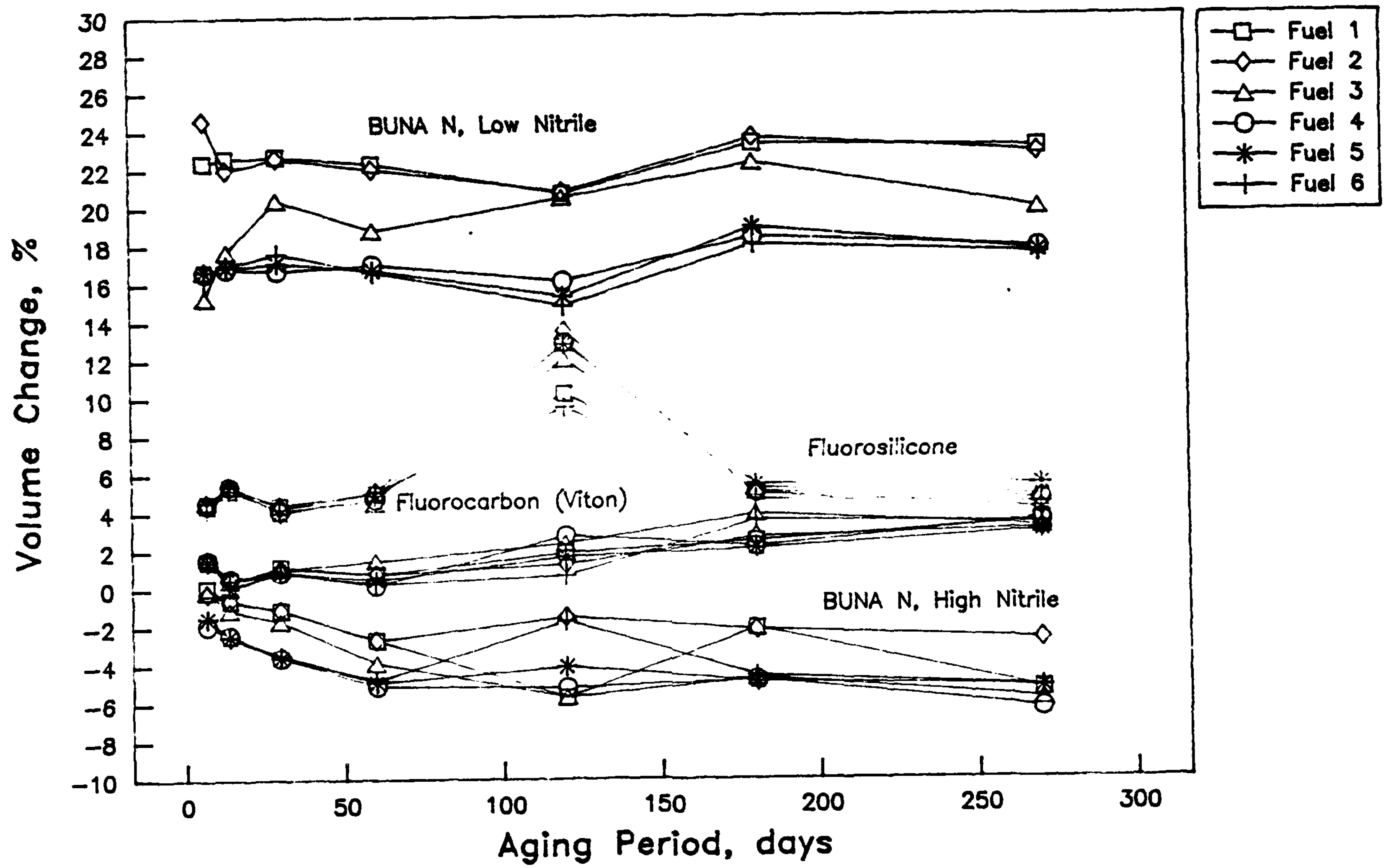

Figure 1. Volume change results for O-ring materials

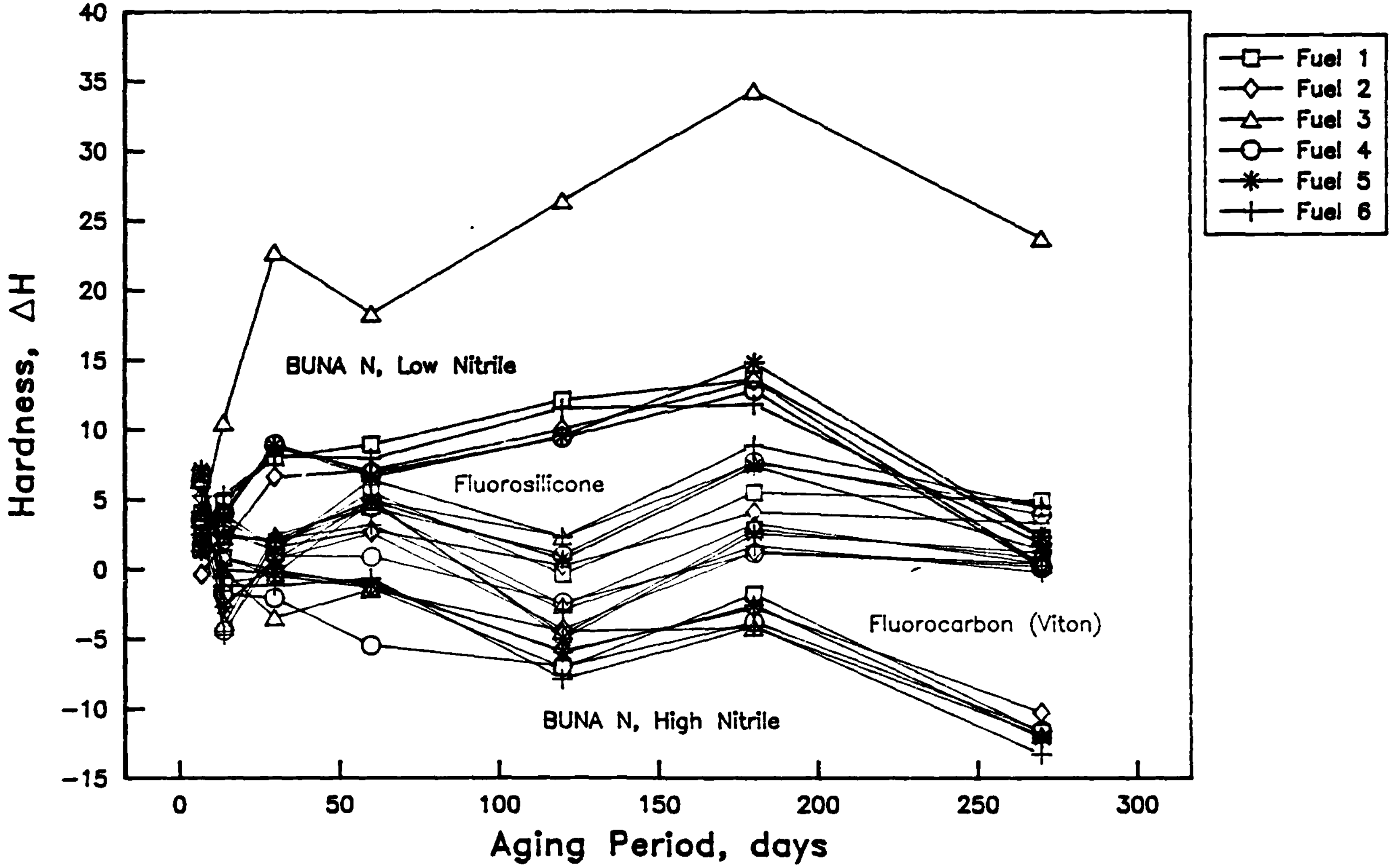

Figure 2. Hardness change results for O-ring materials

TABLE 6. Property Data for Neoprene Diaphragm Material

Storage Period, days	Fuel	Elongation, %	Retained Tensile Strength, %
7	1	30	111.6
	2	11	58.5
	3	19	91.7
	4	27	103.5
	5	11	111.0
	6	23	106.2
14	1	28	113.4
	2	29	120.7
	3	29	119.2
	4	17	93.5
	5	24	108.9
	6	29	127.0
30	1	33	116.8
	2	30	115.8
	3	28	102.6
	4	20	117.3
	5	35	121.8
	6	28	111.8
60	1	28	120.1
	2	25	117.0
	3	5	113.3
	4	3	117.0
	5	25	122.8
	6	19	115.0
120	1	12	109.2
	2	0	84.5
	3	12	119.5
	4	0	83.6
	5	12	96.8
	6	9	99.9
180	1	0	113.4
	2	0	106.2
	3	0	124.9
	4	0	105.6
	5	0	102.6
	6	0	105.6
270	1	20	101.0
	2	20	121.3
	3	22	127.5
	4	0	103.0
	5	0	111.9
	6	0	116.2

TABLE 7. Property Data for CS 3204, B-2 Fuel Tank Sealant Material

Storage Period, days	Fuel	Vol Change, %	Hardness Change, Shore A	Elongation, %	Retained Tensile Strength, %	Retained Peel Strength, %
7	1	1.6	4.1	188	105.9	119.4
	2	1.6	3.6	198	103.5	143.9
	3	0.5	5.6	215	89.4	122.6
	4	0.3	3.4	183	96.3	129.3
	5	0.3	1.9	173	100.0	115.4
	6	0.0	3.0	188	100.7	123.1
14	1	-6.4	-2.0	317	108.0	115.3
	2	-7.7	-2.6	252	96.5	95.4
	3	0.9	2.0	270	94.6	79.1
	4	-5.4	-1.2	242	102.4	107.4
	5	-4.0	-2.0	253	103.9	95.4
	6	-10.0	-2.9	233	97.7	84.8
30	1	0.9	1.5	274	107.1	60.8
	2	0.9	0.8	246	98.7	55.4
	3	1.0	10.9	304	73.8	88.4
	4	-0.7	-2.0	222	109.5	92.2
	5	-0.6	-2.4	206	107.9	89.1
	6	-0.2	-2.6	208	115.9	57.6
60	1	0.8	-0.2	250	104.3	103.8
	2	1.0	1.5	242	104.3	102.0
	3	0.1	7.2	241	66.6	115.2
	4	-1.2	-2.1	189	95.1	65.4
	5	-1.0	1.4	254	107.1	100.8
	6	-1.5	-2.5	230	112.7	74.2
120	1	1.5	-2.0	195	107.1	105.1
	2	1.0	0.6	185	97.5	115.3
	3	0.8	3.9	215	87.0	100.1
	4	-0.5	0.0	170	103.9	94.1
	5	-0.2	0.6	168	100.0	111.4
	6	0.0	1.5	153	100.7	111.2
180	1	1.4	2.5	161	91.8	106.0
	2	0.6	1.8	141	100.3	95.6
	3	-0.4	4.0	165	76.2	97.4
	4	-0.8	2.1	168	106.7	104.4
	5	-1.2	0.8	170	95.1	94.3
	6	-0.4	1.8	168	101.9	97.7
270	1	2.3	3.8	252	93.9	87.9
	2	0.5	5.1	180	85.6	69.8
	3	-0.6	2.1	212	85.6	99.3
	4	-1.1	0.9	185	96.3	70.7
	5	0.1	0.8	227	95.9	71.4
	6	-1.0	2.0	170	101.1	66.5

TABLE 8. Property Data for PS 890, B-2 Fuel Tank Sealant Material

Storage Period, days	Fuel	Vol Change, %	Hardness Change, Shore A	Elongation, %	Retained Tensile Strength, %	Retained Peel Strength, %
7	1	-21.0	0.4	294.2	101.2	95.6
	2	-22.4	-0.5	274.3	84.3	98.4
	3	-21.2	1.9	253.4	101.5	115.2
	4	-24.9	1.6	233.4	85.0	115.2
	5	-24.2	-1.2	259.1	92.6	104.1
	6	-22.5	-0.6	284.7	102.1	115.7
14	1	29.1	4.2	115.3	83.4	95.8
	2	28.6	6.2	124.8	80.1	91.0
	3	29.9	7.2	168.9	65.2	106.9
	4	30.8	5.4	142.4	79.1	119.6
	5	32.2	5.6	159.9	82.4	102.3
	6	31.4	6.5	120.0	76.8	79.6
30	1	27.8	-2.2	207.7	95.8	*
	2	27.9	-2.0	241.8	101.4	
	3	29.6	1.5	228.2	82.2	
	4	27.0	-3.4	195.3	101.4	
	5	26.4	-3.0	203.4	110.0	
	6	25.4	-2.6	198.4	110.0	
60	1	27.7	-2.2	260.4	100.5	*
	2	26.3	-1.1	251.1	101.8	
	3	28.2	2.6	325.5	79.6	
	4	24.8	-4.1	241.8	102.6	
	5	24.3	-3.8	232.5	104.8	
	6	25.1	-4.1	210.8	97.1	
120	1	-0.3	-1.9	168.0	100.9	94.9
	2	0.8	-2.1	192.7	103.1	90.7
	3	-1.0	-3.0	160.6	87.7	81.3
	4	-1.8	-6.2	153.1	98.8	77.2
	5	-1.8	-5.2	138.3	106.5	90.1
	6	-1.1	-4.4	163.0	98.4	62.3
180	1	2.2	-0.5	163.0	92.4	73.7
	2	2.0	-0.6	172.9	95.4	78.7
	3	0.4	-2.1	177.8	92.4	91.6
	4	-0.7	-2.9	143.3	100.9	90.1
	5	0.3	-4.2	150.7	97.5	73.9
	6	0.8	-2.0	165.5	106.0	59.5
270	1	2.0	0.6	138.3	88.2	41.1
	2	2.3	1.9	224.8	94.5	54.9
	3	0.6	-0.8	175.4	83.1	58.2
	4	0.0	-0.5	190.2	92.4	69.5
	5	-0.1	-0.2	205.0	100.9	50.7
	6	-0.4	0.9	195.1	92.0	63.0

* Insufficient specimens available.

TABLE 9. Property Data for PR 1422, B-2 Fuel Tank Sealant Material

Storage Period, days	Fuel	Vol Change, %	Hardness Change, Shore A	Elongation, %	Retained Tensile Strength, %	Retained Peel Strength, %
7	1	1.5	1.9	188	87.2	83.4
	2	1.9	2.8	188	96.4	86.4
	3	1.1	1.2	180	77.6	96.2
	4	0.5	-0.8	207	101.3	85.2
	5	-0.4	-0.6	215	87.2	88.7
	6	0.1	-0.5	210	101.0	82.8
14	1	35.3	3.6	146	90.0	83.0
	2	32.1	5.0	91	93.2	93.1
	3	48.9	8.2	147	69.1	78.5
	4	35.0	6.2	129	83.6	81.8
	5	35.0	5.8	122	84.3	89.9
	6	32.7	5.0	137	93.2	94.5
30	1	26.3	-0.1	219	95.7	93.7
	2	23.5	0.8	183	91.4	89.5
	3	29.8	0.6	273	82.6	89.1
	4	32.8	-0.2	234	93.2	92.9
	5	27.7	-0.6	248	105.6	101.6
	6	23.0	-0.1	214	101.0	95.4
60	1	32.9	-0.2	160	102.1	95.5
	2	29.1	-1.8	259	111.3	79.6
	3	34.6	7.5	226	57.4	97.0
	4	33.7	-2.8	179	80.8	90.3
	5	26.6	-1.8	216	112.0	94.9
	6	29.9	-3.8	190	102.1	102.8
120	1	3.0	6.5	278	94.6	98.8
	2	2.7	2.6	271	96.5	88.1
	3	1.2	2.6	283	93.2	95.5
	4	0.7	3.6	292	95.7	88.9
	5	1.1	2.0	271	91.6	81.2
	6	1.4	1.9	271	92.4	88.3
180	1	4.0	1.6	205	95.7	109.5
	2	3.8	2.9	206	88.6	87.8
	3	1.9	3.9	207	82.6	82.6
	4	1.6	0.4	197	101.0	90.4
	5	2.4	1.9	228	105.6	86.8
	6	2.9	0.9	119	87.2	98.0
270	1	2.8	6.0	247	86.5	90.7
	2	3.7	6.9	254	95.0	101.0
	3	1.8	3.6	245	90.0	101.6
	4	-0.4	4.0	240	92.1	92.7
	5	1.7	2.8	165	81.5	77.3
	6	1.7	5.1	227	99.6	99.8

TABLE 10. Property Data for PS 899, B-2 Fuel Tank Sealant Material

Storage Period, days	Fuel	Vol Change, %	Hardness Change, Shore A	Elongation, %	Retained Tensile Strength, %	Retained Peel Strength, %
7	1	1.4	1.0	173	114.0	80.8
	2	1.1	1.4	128	104.7	86.5
	3	-0.2	1.5	180	121.7	87.5
	4	-0.4	1.8	173	124.1	78.0
	5	-0.2	1.4	180	122.1	89.5
	6	-0.2	2.8	188	122.5	90.0
14	1	28.1	-1.4	120	75.9	*
	2	29.0	-1.1	156	87.9	*
	3	25.6	1.4	114	59.4	*
	4	23.4	-1.4	100	72.0	*
	5	25.5	-2.1	137	82.5	*
	6	25.4	-1.8	126	81.9	*
30	1	0.2	1.5	160	100.8	87.2
	2	0.2	0.2	209	106.6	87.2
	3	0.0	1.9	206	98.5	82.4
	4	-1.3	-0.9	229	119.8	80.6
	5	-1.9	-3.0	146	93.4	86.7
	6	-1.5	0.9	218	119.0	85.9
60	1	-0.9	-5.9	239	117.1	77.7
	2	-0.3	-5.5	221	113.6	72.7
	3	-3.5	-3.2	208	88.4	72.9
	4	-4.1	-8.6	164	106.6	66.0
	5	-5.1	-9.2	220	121.0	65.7
	6	-3.6	-10.0	170	100.8	75.0
120	1	1.5	-0.6	235	87.6	87.0
	2	1.3	2.6	215	84.9	83.6
	3	0.9	0.2	138	87.6	77.7
	4	0.6	-5.0	230	95.8	92.9
	5	-0.6	-3.9	168	76.0	97.0
	6	-0.2	-1.6	178	83.0	87.0
180	1	2.8	4.6	[illegible]	75.3	75.5
	2	3.4	2.6	316	80.1	71.1
	3	1.9	2.1	356	71.4	70.8
	4	2.5	0.4	296	85.8	74.2
	5	1.5	1.9	370	90.0	74.2
	6	1.3	-1.4	227	63.9	73.7
270	1	3.3	1.1	294	74.4	72.1
	2	3.5	3.0	267	70.0	79.3
	3	1.6	3.8	230	74.4	79.6
	4	1.5	2.9	277	82.6	81.3
	5	-3.5	-0.1	203	80.6	76.4
	6	6.9	0.2	272	89.2	81.6

* Specimens lost in handling.

TABLE 11. Property Data for PR 1221, B-2 Fuel Tank Sealant Material

Storage Period, days	Fuel	Vol Change, %	Hardness Change, Shore A	Elongation, %	Retained Tensile Strength, %	Retained Peel Strength, %
7	1	-0.8	2.4	519	77.8	118.1
	2	-1.7	1.1	395	63.6	105.9
	3	-0.2	3.1	403	78.5	98.5
	4	-2.7	1.1	262	48.0	111.9
	5	-3.0	2.0	361	66.3	101.5
	6	-2.6	1.1	479	73.8	109.2
14	1	-1.3	0.6	268	69.7	109.9
	2	-1.1	0.0	272	77.8	95.3
	3	-2.0	-1.8	272	106.9	90.8
	4	-3.3	0.9	371	89.3	86.7
	5	-2.7	1.4	312	88.0	97.1
	6	-3.2	0.9	313	80.0	107.5
30	1	-0.6	0.0	530	94.7	89.2
	2	-0.9	-0.6	476	85.3	89.2
	3	-1.8	-5.8	510	113.7	108.9
	4	-2.1	-2.8	487	102.2	86.9
	5	-2.1	-2.0	524	81.2	86.6
	6	-1.7	-2.1	549	96.8	95.0
60	1	-1.2	-4.0	292	71.1	106.9
	2	-2.2	-5.5	330	104.2	91.7
	3	-2.0	-7.1	356	92.0	103.0
	4	-2.0	-4.6	373	73.8	88.1
	5	-2.1	-3.5	398	77.2	89.2
	6	-2.1	-5.2	250	75.8	105.3
120	1	3.3	0.6	413	102.1	90.8
	2	3.4	-1.6	431	106.3	92.9
	3	-0.1	-0.2	338	94.8	123.3
	4	1.3	1.9	434	97.4	78.3
	5	1.4	0.5	407	111.0	89.6
	6	1.8	2.8	383	90.6	74.5
180	1	1.3	-3.4	420	88.7	89.4
	2	2.0	-3.9	432	99.5	84.5
	3	-0.8	-1.0	494	108.3	86.6
	4	0.8	-1.0	514	93.4	87.5
	5	0.2	-4.5	375	88.7	81.3
	6	1.2	-1.6	358	93.4	69.1
270	1	4.6	0.8	403	104.2	76.4
	2	4.5	-0.2	385	101.5	86.1
	3	0.9	-4.2	336	111.0	71.5
	4	1.7	-2.9	267	96.1	83.7
	5	1.6	-1.2	237	96.1	88.9
	6	2.2	-2.5	304	99.5	83.7

Fig. 3 illustrates the volume change results for the fuel tank sealants. At 120 days and beyond, all five materials showed virtually no volume change. Prior to 120 days, PS 890 showed a large initial volume decrease followed by a significant increase. PS 899 and PR 1422 both underwent large increases for the same period, especially the latter in Fuel 3.

Results for Fuel Cell Materials

TABLES 12 through 15 contain the property data obtained for the fuel cell type elastomers. No consistent effects on elongation or tensile strength retention are evident. The high-peroxide content Fuel 3 was notable in some cases, particularly with respect to reduced tensile strength in the later stages of storage for 51956 Buna-N (TABLE 12) and the polyurethane material (TABLE 13).

Volume change results for the fuel cell elastomers are plotted in Fig. 4. This property change was generally moderate except for the polyurethane material which showed volume increases greater than the other materials. Once again, Fuel 3 was distinguished by the fact that this sample evidenced the highest change, after 30 days of storage.

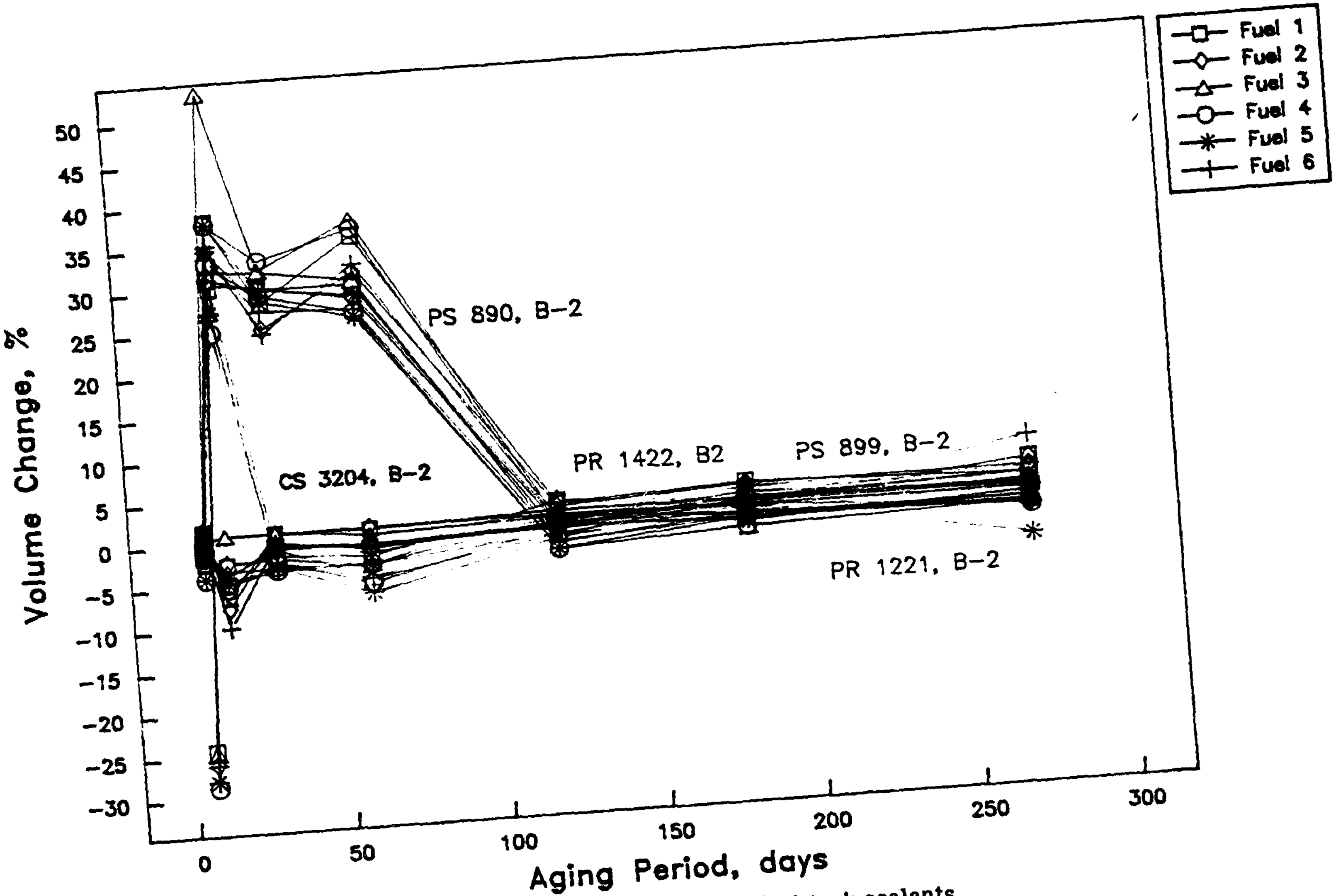

Figure 3. Volume change results for fuel tank sealants

TABLE 12. Property Data for 51956 Buna-N Fuel Cell Material

Storage Period, days	Fuel	Vol Change, %	Elongation, %	Retained Tensile Strength, %
7	1	-4.4	245	88.7
	2	-4.6	247	95.2
	3	-6.9	230	36.0
	4	-8.5	225	97.6
	5	-7.3	254	106.4
	6	-6.9	220	82.9
14	1	-6.3	299	90.1
	2	-7.0	353	86.7
	3	-6.5	219	72.4
	4	-7.9	318	101.3
	5	-7.0	363	96.2
	6	-8.4	334	94.5
30	1	-1.6	288	86.7
	2	-3.8	298	87.7
	3	-7.0	148	52.7
	4	-7.4	369	115.6
	5	-8.1	346	94.5
	6	-8.1	299	93.5
60	1	-3.0	276	102.7
	2	-3.8	322	98.2
	3	-7.4	144	59.5
	4	-6.9	352	115.6
	5	-6.2	321	105.0
	6	-8.7	280	96.2
120	1	-8.1	274	83.6
	2	-5.9	259	103.3
	3	-8.1	121	63.6
	4	-8.2	279	104.7
	5	-8.7	274	110.5
	6	-9.3	212	99.9
180	1	-4.2	291	102.8
	2	-3.7	304	92.8
	3	-8.8	128	78.6
	4	-7.0	304	100.2
	5	-6.6	252	104.1
	6	-5.9	291	102.6
270	1	-3.0	217	87.7
	2	-4.6	230	106.1
	3	-10.1	42	50.6
	4	-7.9	225	91.1
	5	-7.3	245	102.3
	6	-7.6	215	108.4

TABLE 13. Property Data for 80C29 Polyurethane Fuel Cell Material

Storage Period, days	Fuel	Vol Change, %	Elongation, %	Retained Tensile Strength, %
7	1	17.0	235	62.9
	2	16.8	136	78.0
	3	16.3	264	84.8
	4	10.8	262	87.0
	5	11.5	247	75.9
	6	11.2	245	82.0
14	1	20.7	325	67.5
	2	19.9	353	56.7
	3	15.8	363	87.6
	4	14.6	-	66.2
	5	15.4	291	55.4
	6	16.2	327	74.4
30	1	30.4	300	74.0
	2	29.1	291	58.2
	3	15.8	495	56.6
	4	5.8	331	89.4
	5	6.7	260	91.1
	6	24.6	308	94.4
60	1	20.3	324	63.8
	2	21.0	344	71.1
	3	27.4	482	19.3
	4	15.3	348	83.2
	5	15.4	334	61.9
	6	15.6	354	97.4
120	1	*	326	65.7
	2	*	185	55.9
	3	*	452	8.0
	4	*	348	83.2
	5	*	287	65.0
	6	*	264	81.1
180	1	19.2	296	83.8
	2	21.7	269	70.0
	3	31.4	287	6.5
	4	16.3	252	78.0
	5	11.7	279	95.5
	6	15.6	254	91.9
270	1	21.2	220	75.1
	2	21.6	319	62.2
	3	28.1	259	4.4
	4	14.9	299	62.5
	5	16.8	225	76.8
	6	16.1	272	76.7

* Specimens lost in handling.

TABLE 14. Property Data for FT76 Buna-N Fuel Cell Material

Storage Period, days	Fuel	Vol Change, %	Elongation, %	Retained Tensile Strength, %
7	1	0.5	5	98.6
	2	1.2	0	108.2
	3	-0.8	0	99.1
	4	-1.5	10	96.9
	5	-2.4	0	92.8
	6	-1.2	7	95.8
14	1	2.8	24	97.4
	2	2.9	36	103.7
	3	2.8	22	106.2
	4	0.7	33	110.8
	5	1.0	9	98.6
	6	0.9	19	107.7
30	1	-0.2	44	95.8
	2	-1.2	42	99.9
	3	-1.3	40	113.8
	4	-1.7	36	95.8
	5	-3.2	40	94.6
	6	-2.5	28	99.1
60	1	3.1	31	99.1
	2	2.8	28	94.3
	3	3.4	22	88.3
	4	3.5	18	85.5
	5	1.5	18	85.0
	6	0.9	20	115.3
120	1	7.5	24	93.3
	2	6.0	12	101.5
	3	-2.0	0	95.3
	4	-1.8	0	86.9
	5	0.8	0	96.1
	6	6.8	0	92.9
180	1	7.6	22	110.8
	2	1.2	25	100.6
	3	1.5	22	109.5
	4	-6.1	20	113.3
	5	-3.0	20	89.3
	6	1.2	25	96.1
270	1	4.0	22	83.4
	2	4.5	22	109.0
	3	4.4	25	86.7
	4	1.5	35	101.7
	5	1.5	37	98.9
	6	0.5	20	93.1

TABLE 15. Property Data for Nylon Pliocel Fuel Cell Material

Storage Period, days	Fuel	Vol Change, %	Elongation, %	Retained Tensile Strength, %
7	1	2.6	21	101.5
	2	0.5	24	109.5
	3	5.3	17	95.0
	4	-1.3	17	113.3
	5	0.2	30	103.4
	6	1.2	22	103.8
14	1	-1.9	34	106.1
	2	-2.6	34	104.4
	3	0.5	45	94.5
	4	-2.2	45	101.3
	5	-2.9	55	106.1
	6	-2.0	42	99.0
30	1	6.3	25	105.4
	2	1.1	38	114.3
	3	8.2	*	107.9
	4	1.9	*	108.6
	5	3.7	*	107.9
	6	2.4	*	112.7
60	1	1.8	56	117.1
	2	1.1	40	116.3
	3	9.3	33	106.1
	4	0.3	30	116.0
	5	0.3	56	115.1
	6	2.2	64	113.0
120	1	-4.1	32	107.4
	2	2.7	30	101.7
	3	7.3	27	99.5
	4	-2.9	30	106.5
	5	-2.1	35	110.8
	6	3.7	35	111.1
180	1	1.0	17	97.4
	2	3.8	20	100.0
	3	8.7	35	93.2
	4	-0.1	20	99.1
	5	2.3	22	95.3
	6	5.5	17	94.5
270	1	1.0	25	114.4
	2	1.7	42	106.5
	3	11.0	32	88.9
	4	-2.4	22	106.8
	5	-0.5	17	117.1
	6	13.2	25	96.3

* Specimens lost in handling.

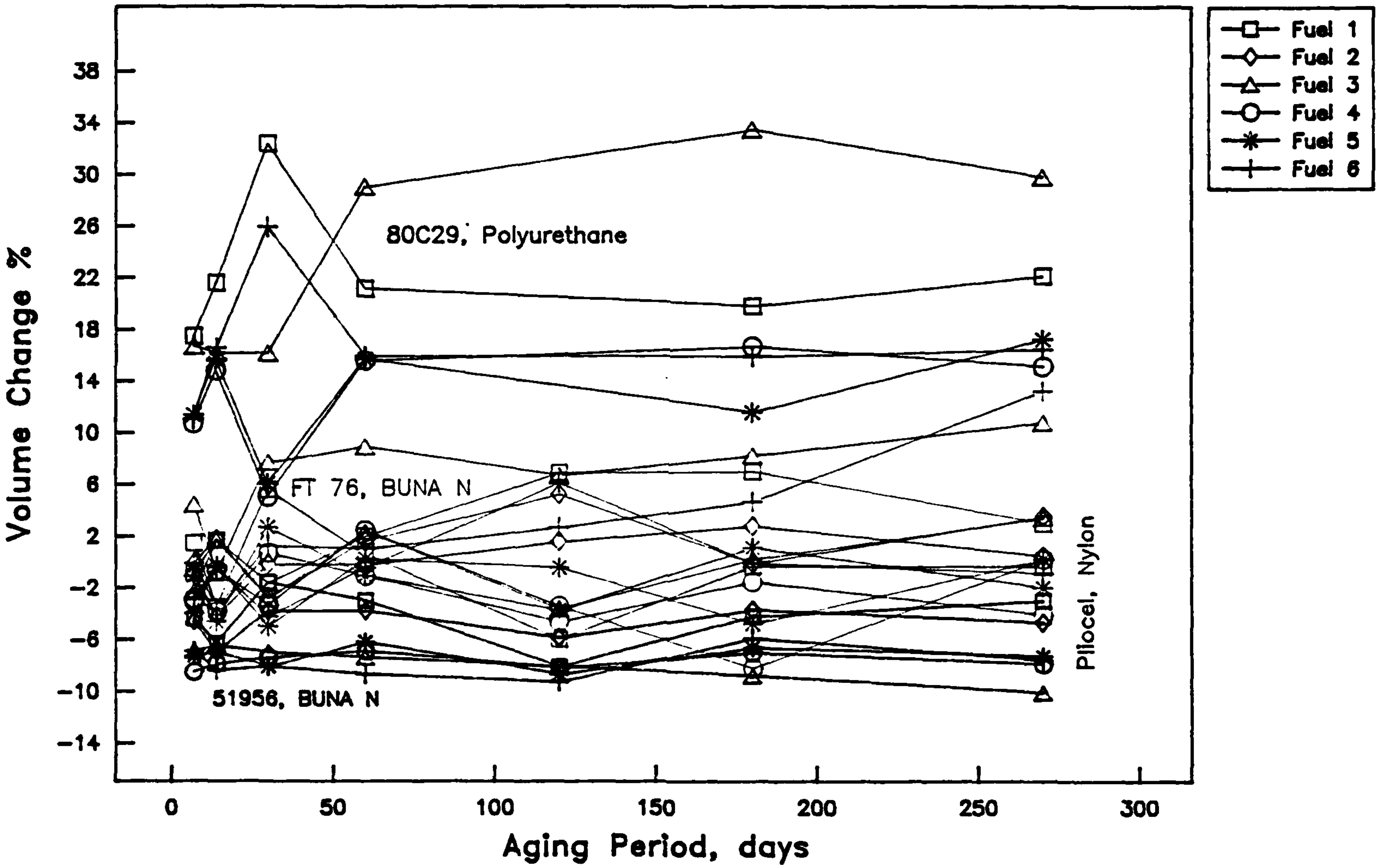

Figure 4. Volume change results for fuel cell materials

V. CONCLUSIONS

Based on the findings of this investigation, the following conclusions have been derived:

- Following prestressing and 270-day storage, peroxide analyses showed very effective peroxidation suppression by the totally hindered AO-B antioxidant, 2-6-di-tert-butyl-4-methylphenol. Slightly lesser effectiveness was exhibited by the partially hindered AO-D antioxidant, 2-4-di-tert-butylphenol.

- There was no evidence of an antioxidant effect on elastomer properties over the 270-day storage period.

- Variable effects among the elastomers were observed, but the only fuel effect was that shown for the high-peroxide, uninhibited, unstable fuel (Fuel 3). This fuel generally showed the highest change in volume and hardness, and the lowest retention of strength properties.

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